Multiplex interbank networks and systemic importance

An application to European data

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Motivation - Multiplex network

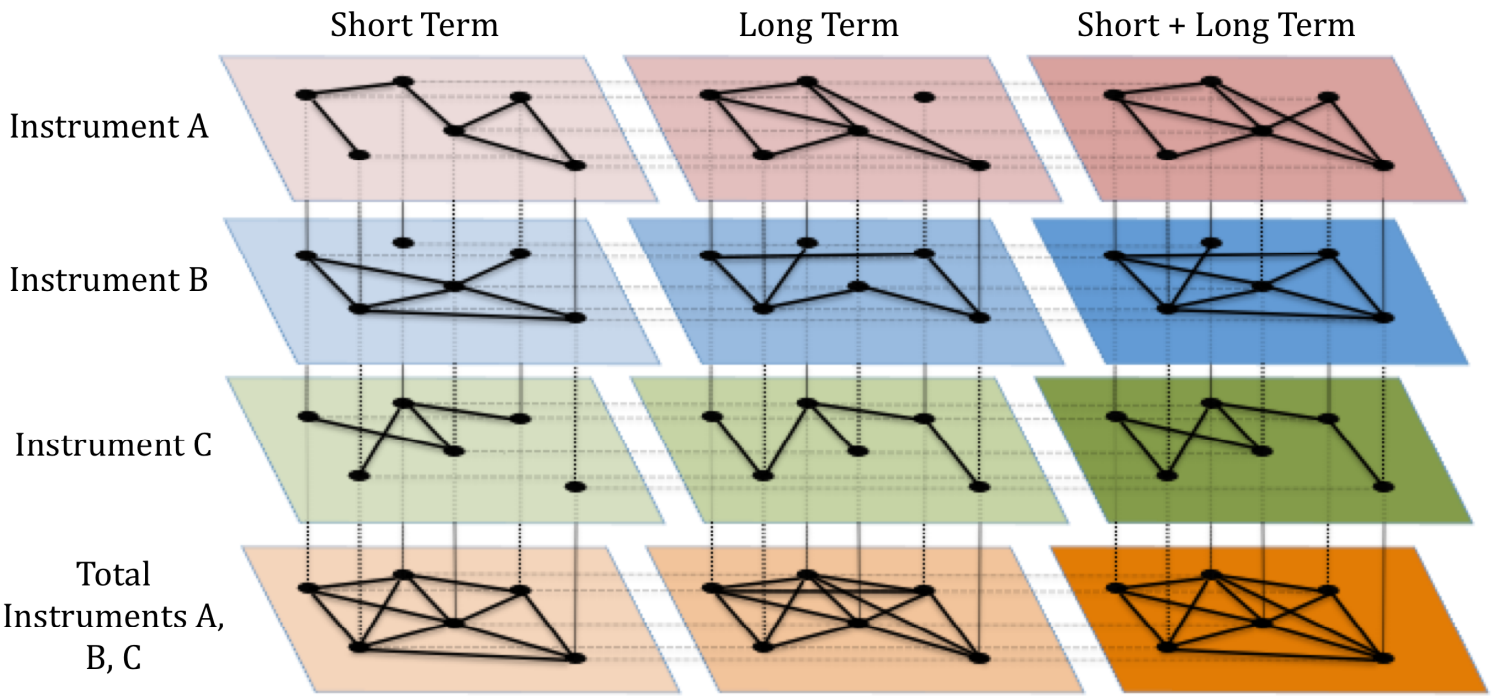

Figure 1 : A stylised representation of a multiplex interbank network.

This paper

- Study the multiplex structure of the network of large European banks
  - Similarity analysis
  - Core-periphery analysis
  - Correlated multiplexity
- Present new measures of systemic importance which allow for a decomposition of the global systemic importance index for any bank into the contributions of each of the sub-networks
- Highlight important policy content of the choice of granularity of information in the analysis of systemic importance

Summary

- Existence of connection in one layer strongly associated to existence of the same connection in another layer (high similarity)
- Large core with core-periphery structure rather stable across layers (especially for maturity type)
- Network centrality indicators highly correlated across layers (positively correlated multiplexity)

Summary

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- Large core with core-periphery structure rather stable across layers (especially for maturity type)
- Network centrality indicators highly correlated across layers (positively correlated multiplexity)

Yet ...

- Taking a holistic perspective that goes beyond layer-specific analyses can yield useful insights for policy
- Despite similarity and correlation: core $\neq$ centrality $\neq$ layer-specific contributions to overall systemic importance

Related literature

- Importance of structure of interconnectedness (Allen & Gale '00, Freixas et al. '00)
- Analyses of interconnectedness observable in banks' balance sheets (Boss et al. '04, Craig & von Peter '14, Soramäki et al. '07, van Lelyveld & Int Veld '12, Fricke & Lux '12, Langfield et al. '14, and Alves et al. '13, etc.)
- Systemic importance in interbank networks (Aldasoro & Angeloni '15, Battiston et al. '12, Soramäki & Cook '13, Greenwood et al. '14)
- Multiplex networks, with focus on interbank (Kivelä et al. '14, Lee et al. '14, Montagna & Kok '13, Langfield et al. '14, León et al. '14, Molina-Borboa et al. '15, Poledna et al. '15)

The Input-Output approach - Single layer case

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  1. Mapping between non-interbank assets ($\mathbf{l}$) and total assets ($\mathbf{q}$)

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  2. Mapping between non-interbank funding ($\mathbf{e} + \mathbf{d}$) to total funding

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- Systemic importance of bank j as backward and forward linkages
  1. Sum of elements in column j of $\mathbf{B}$: $h_{b_j} = \mathbf{i}'\mathbf{B}\mathbf{i}_j$
  2. Sum of elements in row j of $\mathbf{G}$: $h_{f_j} = \mathbf{i}_j'\mathbf{G}\mathbf{i}$

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- A useful property of the Leontief inverse: infinite series

$$\begin{aligned}\mathbf{B} &= (\mathbf{I} - \mathbf{A})^{-1} \\ &= \mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + \cdots \\ &= \mathbf{I} + \mathbf{A}\left(\mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \cdots\right) \\ &= \mathbf{I} + \mathbf{A}\mathbf{B}\end{aligned}$$

The case of many layers (cont.)

- Using this and noting that $\mathbf{A} = \sum_{\alpha=1}^{L} \mathbf{A}_\alpha$, 2 can be expressed as:

$$\mathbf{q} = \mathbf{B}\mathbf{l} = (\mathbf{I} + \mathbf{A}\mathbf{B})\,\mathbf{l} = \left(\mathbf{I} + \sum_{\alpha=1}^{L} \mathbf{H}_\alpha\right)\mathbf{l} \tag{4}$$

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- Backward linkage index still calculated as before (for bank j: sum of elements in column j of $\mathbf{B}$), but now we are able to attribute to each layer α its contribution to the overall systemic importance index, as measured by the column sum j of the $\mathbf{H}_\alpha$ matrices.

Decomposing systemic importance

- Re-express the matrix $\mathbf{H}_\alpha$ in vector notation:

$$\mathbf{H}_\alpha = \begin{bmatrix} \mathbf{a}'_{\alpha 1}\mathbf{b}_1 & \cdots & \mathbf{a}'_{\alpha 1}\mathbf{b}_n \\ \vdots & \ddots & \vdots \\ \mathbf{a}'_{\alpha n}\mathbf{b}_1 & \cdots & \mathbf{a}'_{\alpha n}\mathbf{b}_n \end{bmatrix} \tag{5}$$

where $\mathbf{a}'_{\alpha i} = i^{th}$ row of matrix $\mathbf{A}_\alpha$ and $\mathbf{b}_j = j^{th}$ column of matrix $\mathbf{B}$.

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where $\mathbf{a}'_{\alpha i} = i^{th}$ row of matrix $\mathbf{A}_\alpha$ and $\mathbf{b}_j = j^{th}$ column of matrix $\mathbf{B}$.

- Share of backward index for bank j attributed to layer α given by sum of elements in column j of $\mathbf{H}_\alpha$:

$$\mathbf{i}'\mathbf{H}_\alpha\mathbf{i}_j = \mathbf{a}'_{\alpha 1}\mathbf{b}_j + \cdots + \mathbf{a}'_{\alpha n}\mathbf{b}_j = \left(\mathbf{a}'_{\alpha 1} + \cdots + \mathbf{a}'_{\alpha n}\right)\mathbf{b}_j \tag{6}$$

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Decomposing systemic importance (cont.)

- Similar decomposition for forward linkages:

$$\mathbf{G} = (\mathbf{I} - \mathbf{O})^{-1} = \mathbf{I} + \mathbf{GO} = \mathbf{I} + \sum_{\alpha=1}^{L} \mathbf{K}_\alpha \tag{7}$$

where $\mathbf{O} = \sum_{\alpha=1}^{L} \mathbf{O}_\alpha$, $\mathbf{O}_\alpha = \hat{\mathbf{q}}^{-1}\mathbf{X}_\alpha$ and $\mathbf{K}_\alpha = \mathbf{GO}_\alpha$, $\alpha = 1, \ldots, L$.

- Matrix $\mathbf{K}_\alpha$ in vector notation

$$\mathbf{K}_\alpha = \begin{bmatrix} \mathbf{g}_1'\mathbf{o}_{\alpha 1} & \cdots & \mathbf{g}_1'\mathbf{o}_{\alpha n} \\ \vdots & \ddots & \vdots \\ \mathbf{g}_n'\mathbf{o}_{\alpha 1} & \cdots & \mathbf{g}_n'\mathbf{o}_{\alpha n} \end{bmatrix} \tag{8}$$

- Share of forward index for bank i attributed to layer α

$$\mathbf{i}_i'\mathbf{K}_\alpha\mathbf{i} = \mathbf{g}_i'\mathbf{o}_{\alpha 1} + \cdots + \mathbf{g}_i'\mathbf{o}_{\alpha n} \tag{9}$$

Overview of the dataset

- Dataset of interbank exposures for 54 large European banks, presented in Alves et al. (2013)
- Anonymized snapshot of interbank exposures at end 2011, compiled by national regulators within a joint EBA-ESRB statistical project
- Two aspects
  1. Instrument type: assets (credit claims + debt securities + other assets), derivatives and off-balance sheet.
  2. Maturity type: short term (less then one year including on sight), long term (more than one year) and unspecified maturity

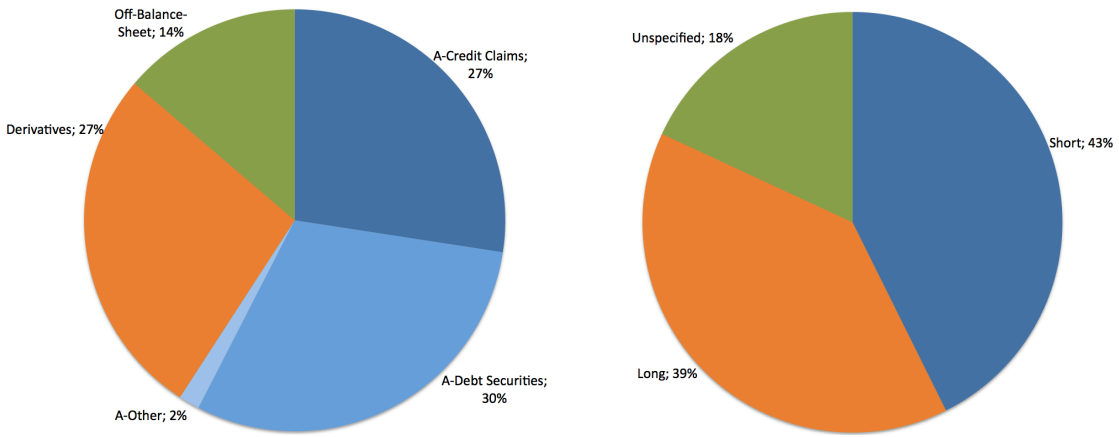
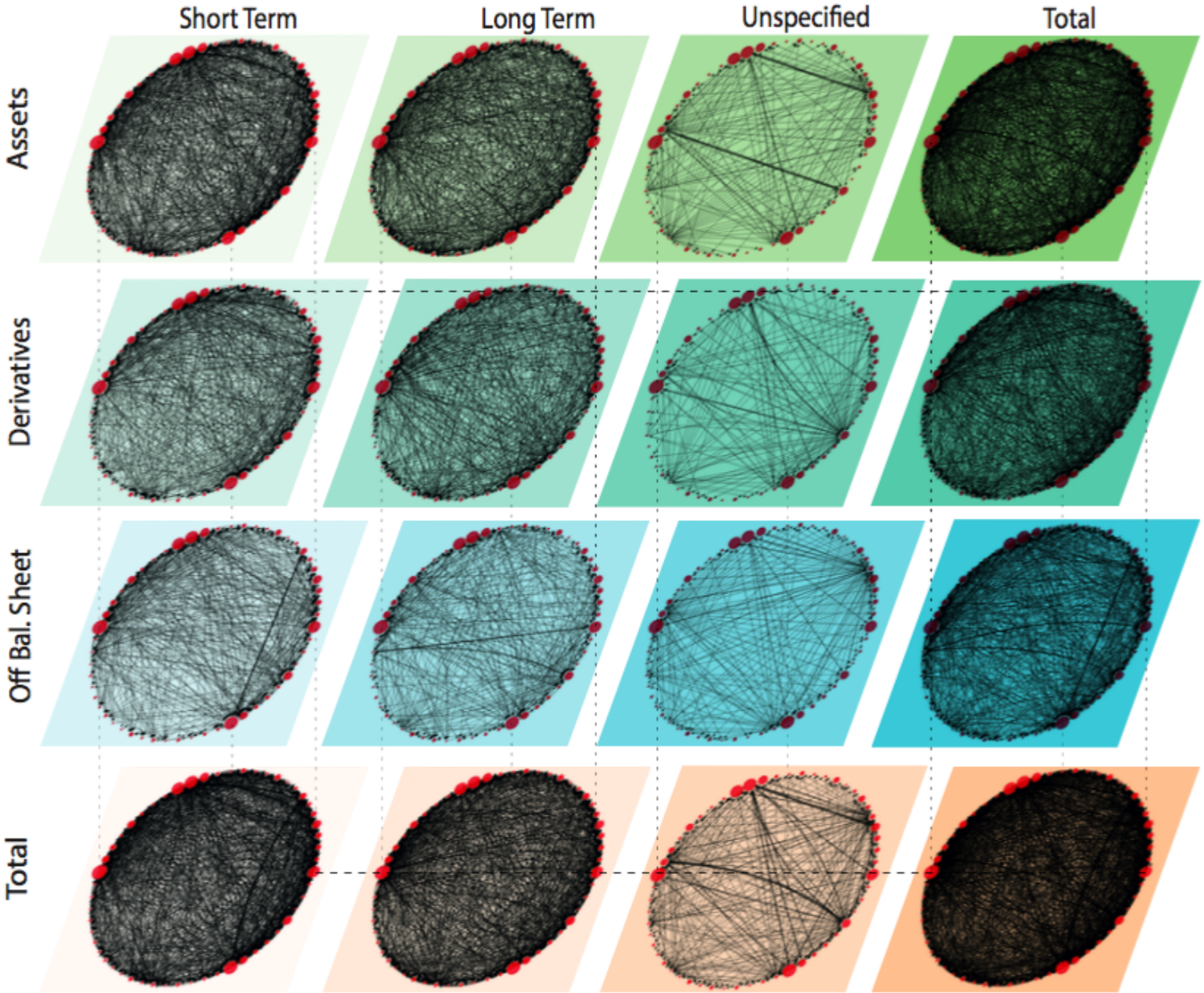


Figure 2 : Composition of exposures by instrument (left) and maturity (right).

The multiplex network of large European banks



Similarity analysis

- Jaccard similarity (binary networks): $J(\mathbf{x}, \mathbf{y}) = \frac{|\mathbf{x} \cap \mathbf{y}|}{|\mathbf{x} \cup \mathbf{y}|}$
- Cosine similarity (weighted networks): $C(\mathbf{x}, \mathbf{y}) = \frac{\mathbf{x} \cdot \mathbf{y}}{||\mathbf{x}|| \times ||\mathbf{y}||}$

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	A-CC	A-DS	A-Other	A-Total	Derivatives	Off BS	Total
A-CC		0.32	0.29	0.80	**0.33**	**0.18**	0.70
A-DS	0.50		0.08	0.82	**0.26**	**0.24**	0.71
A-Other	0.18	0.15		0.29	**0.10**	**0.12**	0.26
A-Total	0.70	0.78	0.16		**0.36**	**0.26**	0.88
Derivatives	**0.50**	**0.46**	**0.15**	**0.53**		**0.13**	0.66
Off BS	**0.44**	**0.37**	**0.16**	**0.41**	**0.41**		0.54
Total	0.57	0.63	0.13	0.81	0.61	0.48	

	Long	Short	Total	Unclassified
Long		**0.43**	0.75	**0.03**
Short	**0.62**		0.81	**0.23**
Total	0.69	0.73		0.50
Unclassified	**0.04**	**0.03**	0.16	

Table 1 : *Jaccard* (lower triangle) and *Cosine* (upper triangle) Similarity Indices, by instrument and maturity type (upper and lower table resp.)

More results

Core-periphery structure - discrete

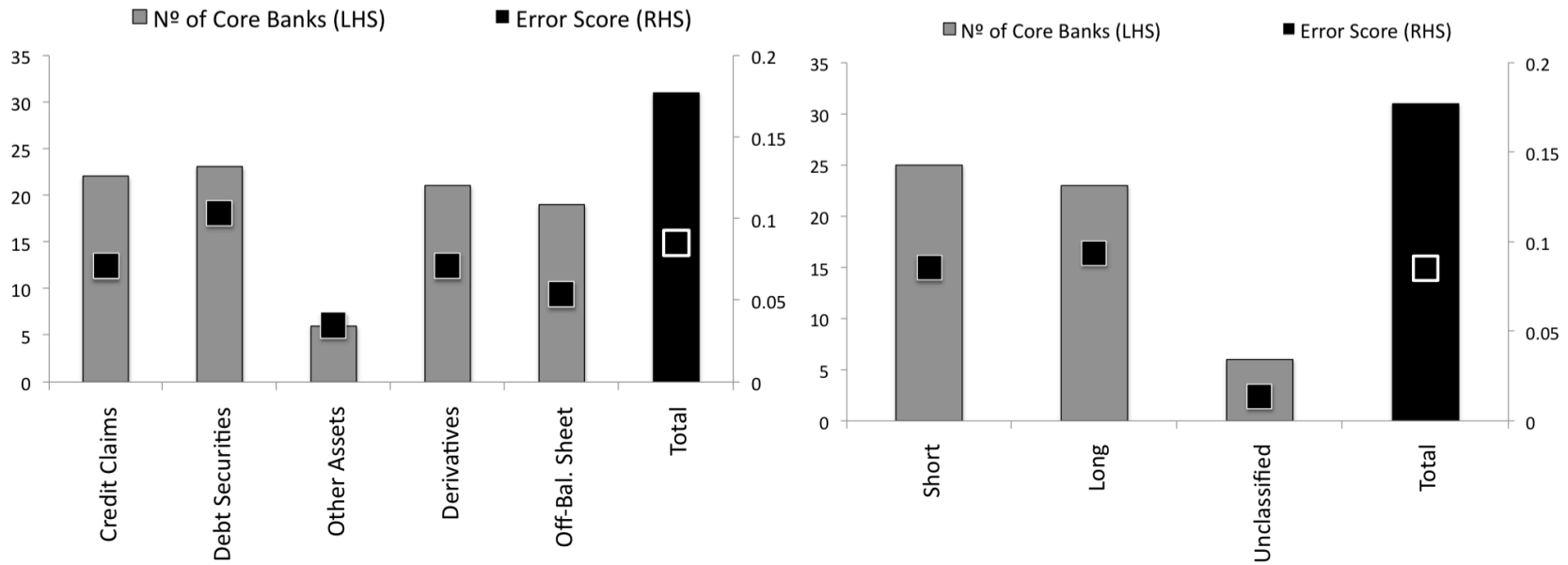

Figure 3 : Core banks and error score based on Craig and von Peter (2014) algorithm, by instrument and maturity (left and right panel respectively).

Core-periphery structure - continuous

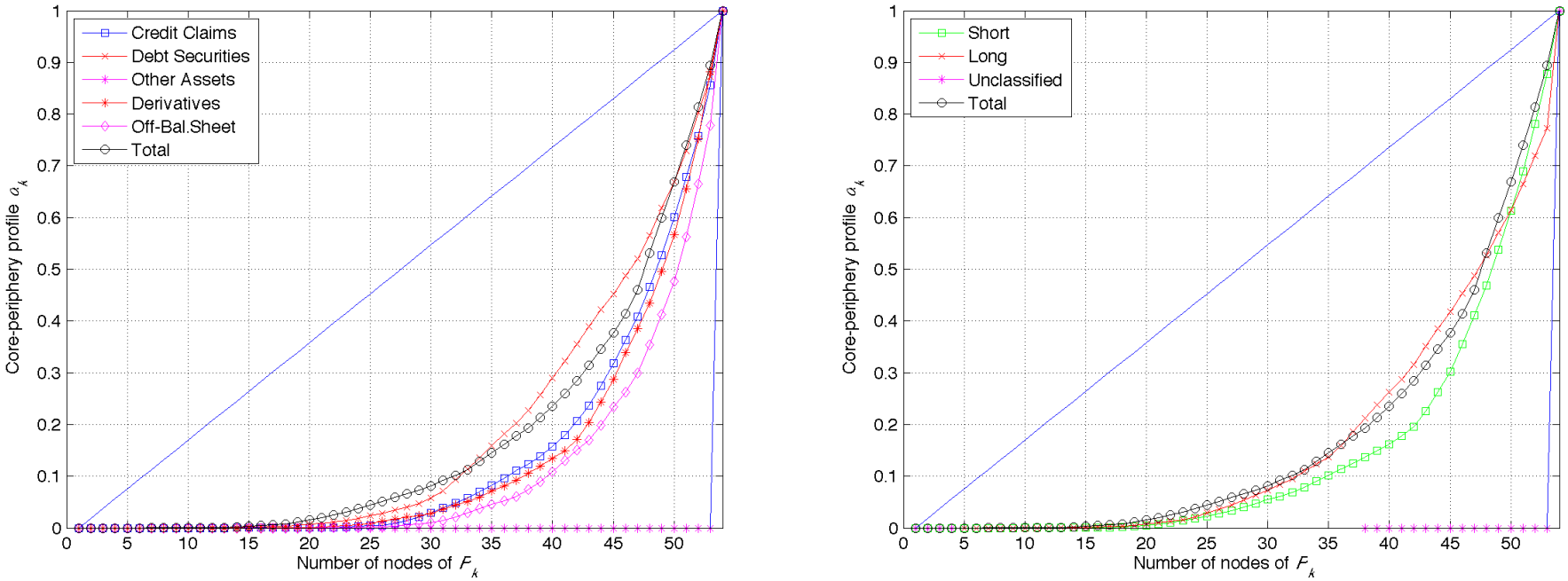

Figure 4 : Core-periphery profile by instrument and maturity (left and right panel respectively), based on the method by Della Rossa et al. (2013).

More results

Systemic importance - Correlated multiplexity

	Assets-L	Assets-S	Deriv.-L	Deriv.-S	OffBS-L	OffBS-S
Assets-L		0.77***	0.64***	0.52***	0.57***	0.44***
Assets-S	0.88***		0.71***	0.58***	0.39***	0.60***
Deriv.-L	0.69***	0.80***		0.72***	0.44***	0.53***
Deriv.-S	0.78***	0.89***	0.90***		0.40***	0.63***
OffBS-L	0.83***	0.87***	0.73***	0.79***		0.52***
OffBS-S	0.84***	0.91***	0.79***	0.86***	0.92***	

Table 2 : Correlation indices for *in*- and *out-degree* centrality (lower and upper triangle resp.)

	Assets-L	Assets-S	Deriv.-L	Deriv.-S	OffBS-L	OffBS-S
Assets-L		0.62***	0.78***	0.14	0.18	0.39***
Assets-S	0.60***		0.45***	0.18	0.07	0.22
Deriv.-L	0.52***	0.71***		0.15	0.16	0.19
Deriv.-S	0.46***	0.75***	0.87***		-0.00	0.16
OffBS-L	0.33**	0.65***	0.52***	0.53***		0.73***
OffBS-S	0.50***	0.80***	0.61***	0.61***	0.56***	

Table 3 : Correlation indices for *PageRank in* (lower triangle) and *out* (upper triangle) centrality.

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- Centrality strongly correlated across layers
- Robust to other centrality measures (strength, closeness, betweenness) and correlation indicators (Spearman). More results

Decomposition of systemic importance

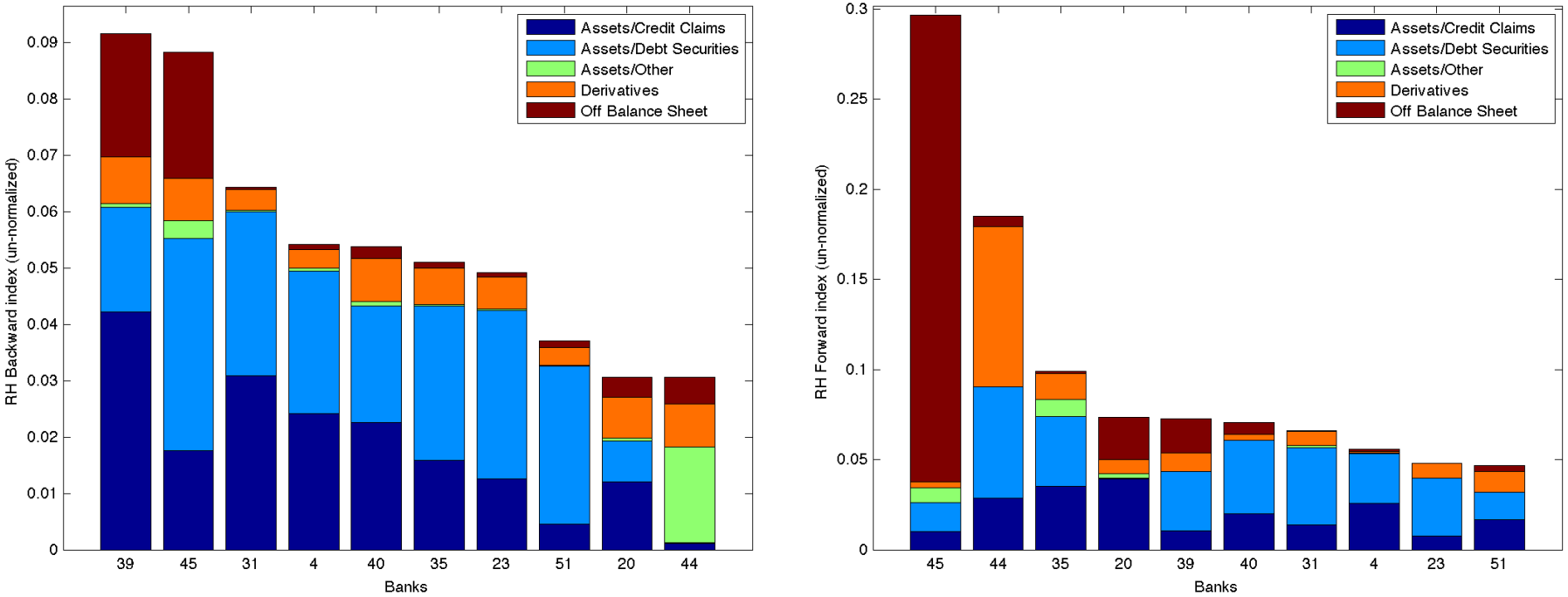
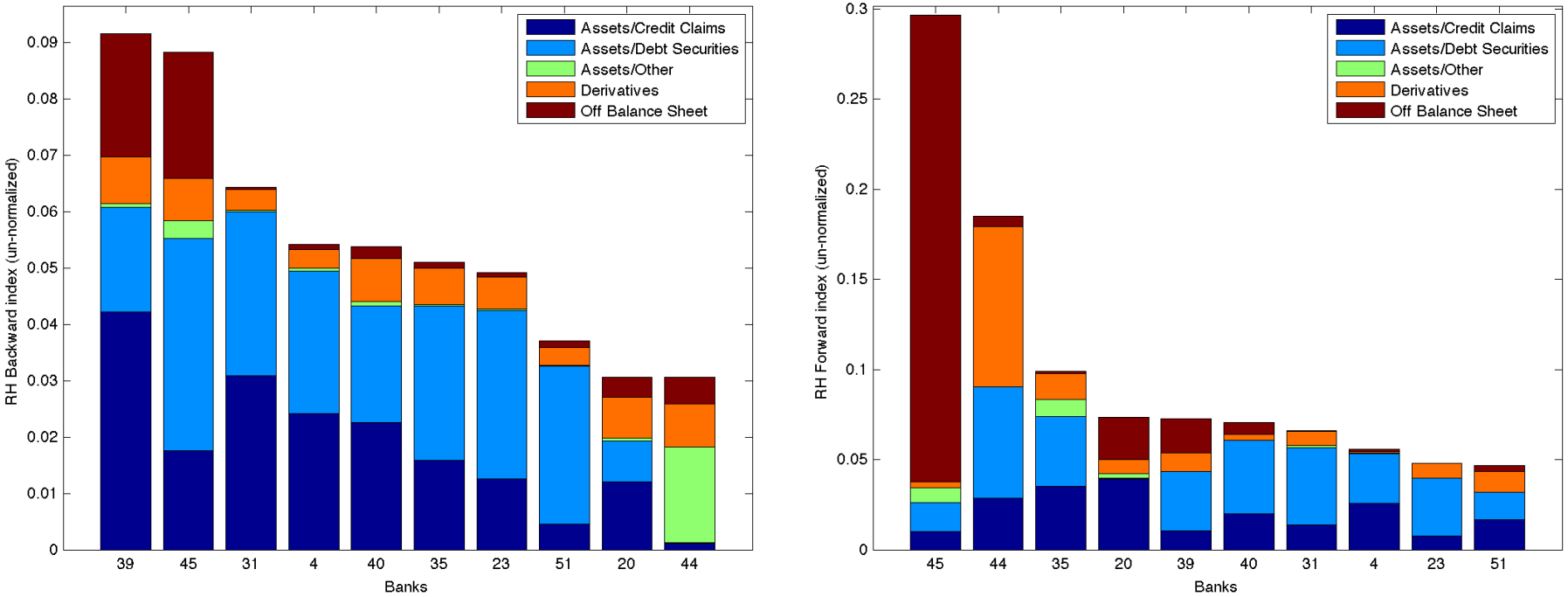


Figure 5 : Backward (left) & forward (right) index for syst. banks by instrument

Decomposition of systemic importance



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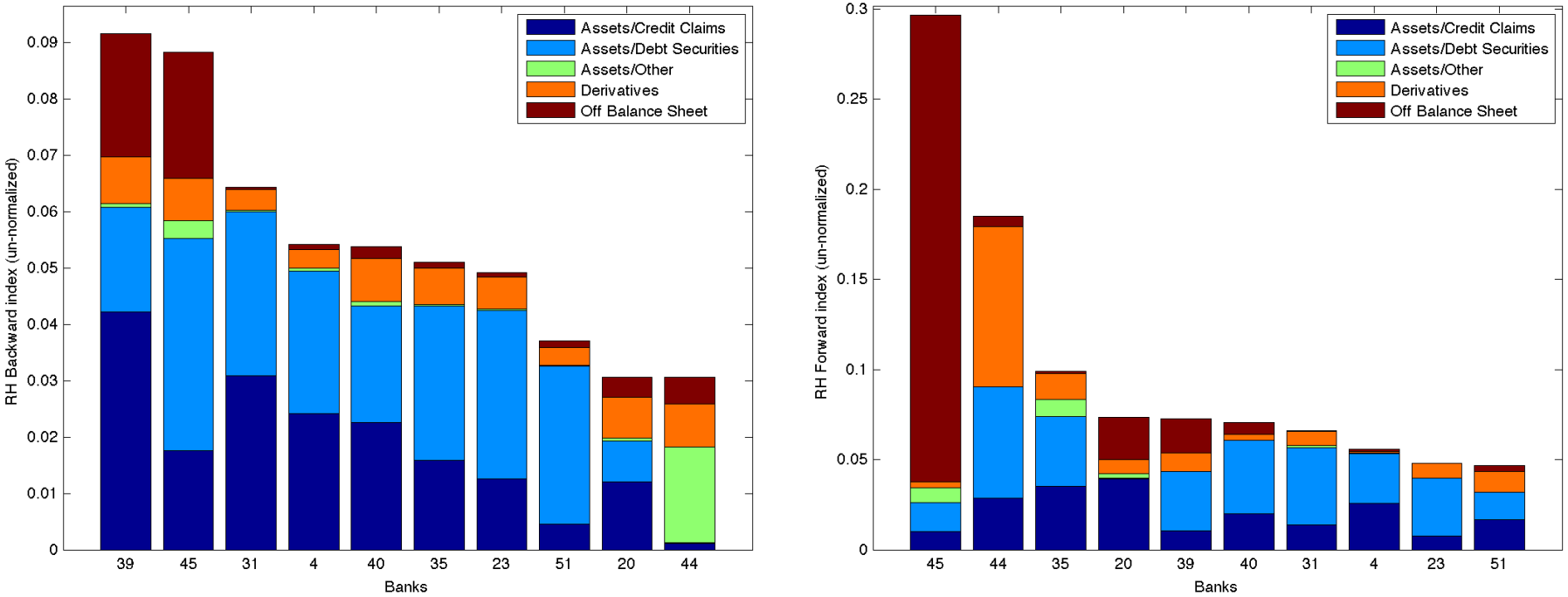

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- Importance in terms of interconnectivity driven by more than size: contribution of *derivatives* not in line with exposure share ($\sim 25\%$)
- A network with a rather minor share of exposures ($OffBS \sim 1/7$) can be a major driver of systemic importance of specific banks

Decomposition of systemic importance (cont.)

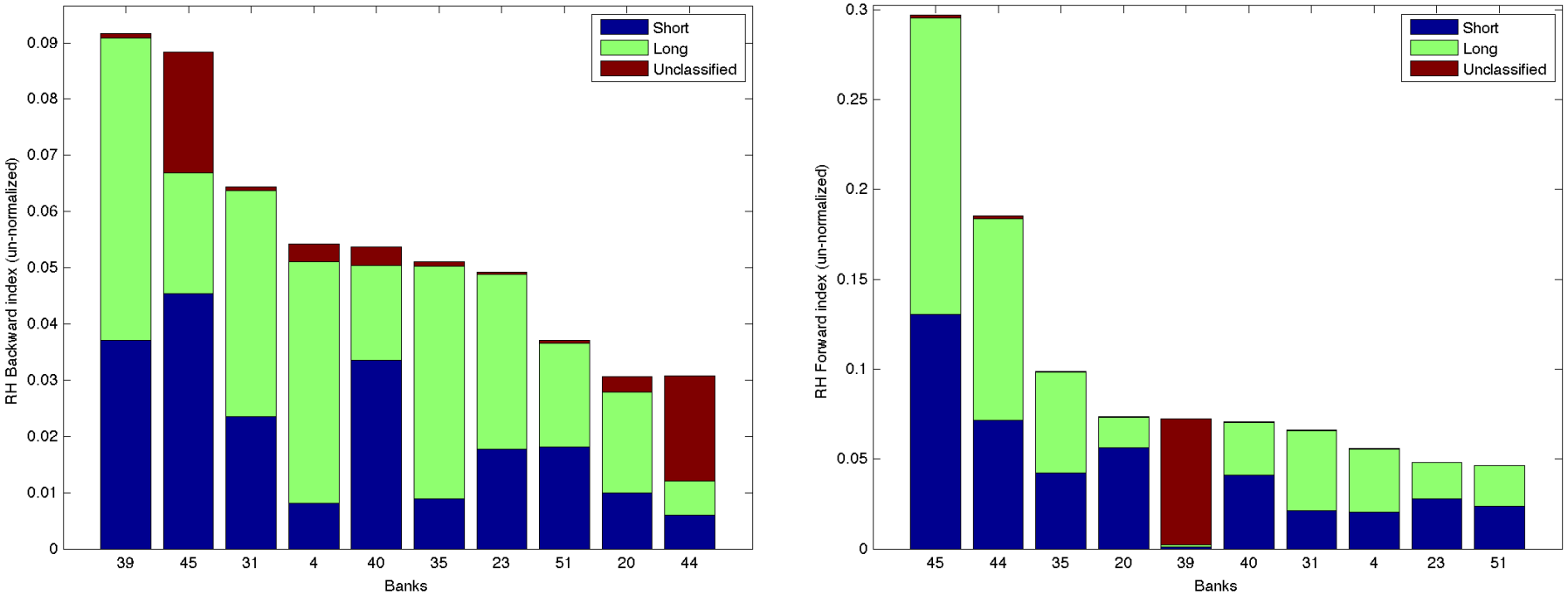
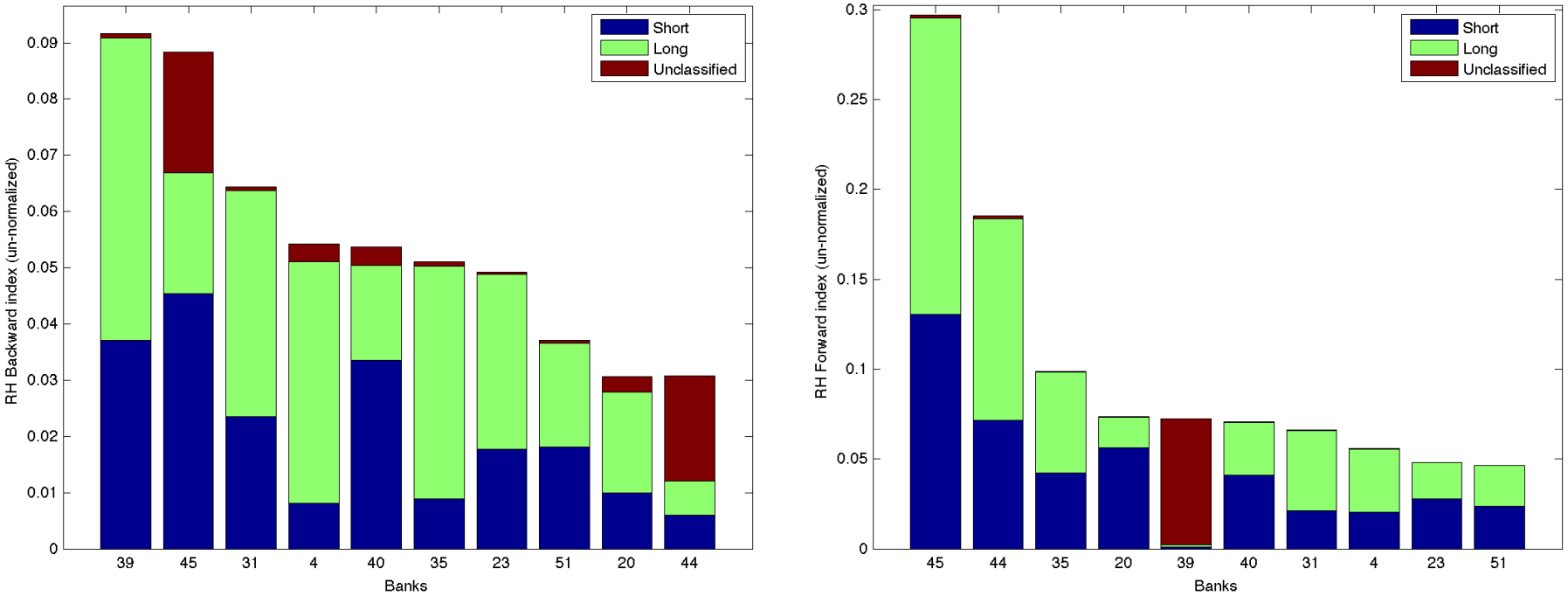


Figure 6 : Backward (left) & forward (right) index for syst. banks by maturity

Decomposition of systemic importance (cont.)



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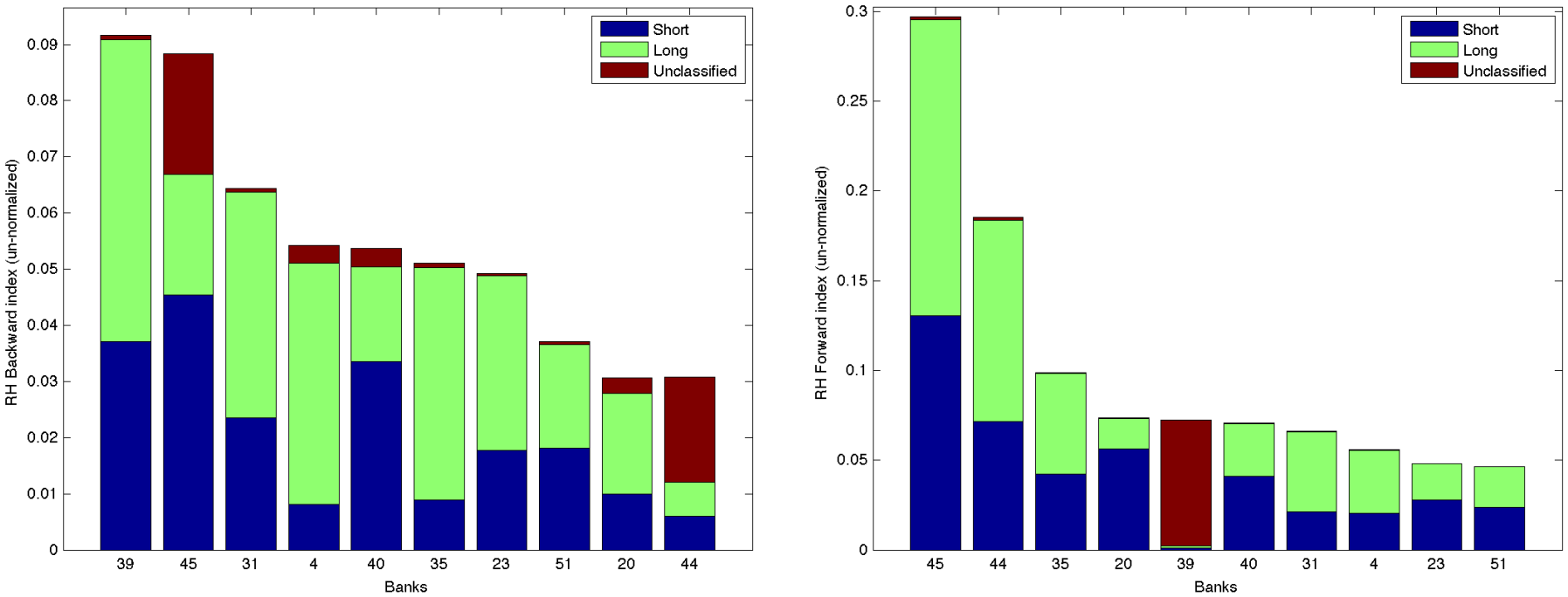

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- *Long term* contributes more than its share in exposures
- *Unspecified maturity* contributes less

Decomposition of systemic importance (cont.)

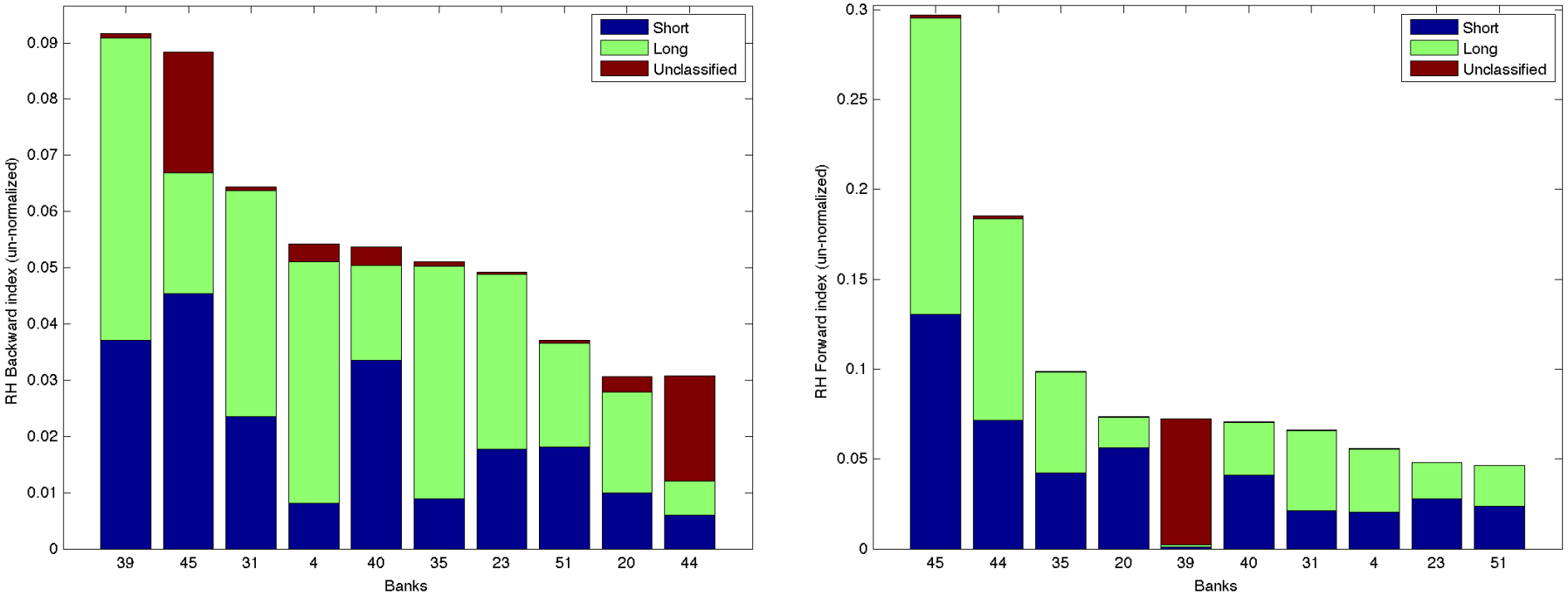

Figure 6 : Backward (left) & forward (right) index for syst. banks by maturity

- *Long term* contributes more than its share in exposures
- *Unspecified maturity* contributes less
- Notable exception forward index of bank 39 $\Longrightarrow$ opacity in banks' operations behind systemic importance score

THANK YOU!

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Additonal results on similarity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) Assets-CC L		0.23	0.33	0.14	0.30	0.14	0.35	0.06	0.08	0.11
(2) Assets-CC S	0.33		0.22	0.13	0.08	0.15	0.24	0.15	0.04	0.12
(3) Assets-DS L	0.31	0.43		0.31	0.07	0.07	0.24	0.09	0.04	0.23
(4) Assets-DS S	0.25	0.37	0.42		0.01	0.05	0.11	0.04	0.05	0.28
(5) Assets-Other L	0.16	0.09	0.09	0.08		0.09	0.13	0.02	0.01	0.01
(6) Assets-Other S	0.13	0.11	0.10	0.11	0.18		0.07	0.03	0.15	0.12
(7) Derivatives L	0.27	0.35	0.35	0.27	0.11	0.11		0.18	0.07	0.11
(8) Derivatives S	0.27	0.40	0.33	0.24	0.09	0.09	0.45		0.02	0.06
(9) OffBS L	0.35	0.25	0.26	0.23	0.11	0.09	0.23	0.23		0.36
(10) OffBS S	0.32	0.38	0.27	0.26	0.11	0.10	0.29	0.34	0.31	

Table 4 : *Jaccard* (lower triangle) and *Cosine* (upper triangle) Similarity Indices, by instrument and maturity type. CC stands for Credit Claims, DS stands for Debt Securities, and L (S) stands for Long (Short) Term.

Back to similarity.

Additonal results on continuous core-periphery analysis

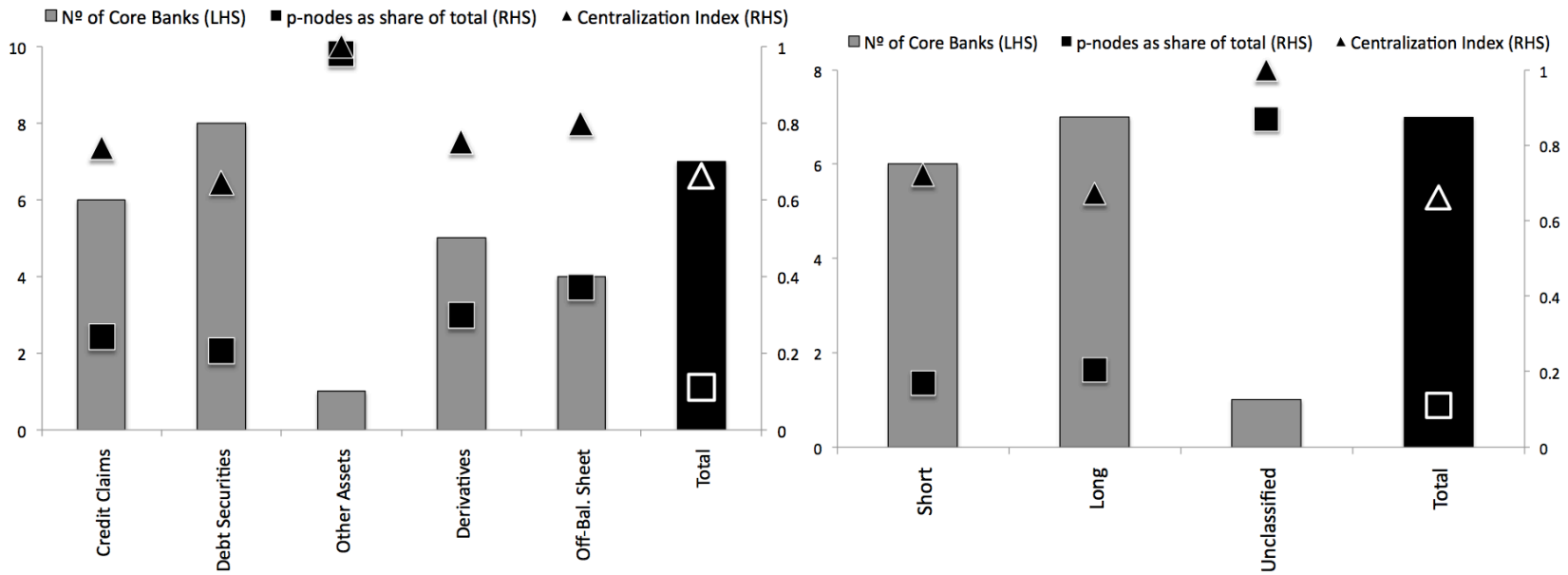

Figure 7 : Core banks, p-nodes and centralisation by instrument and maturity (left and right panel respectively), based on the method by Della Rossa et al. (2013). Core banks are those with $\alpha_k > 0.5$; p-nodes are periphery nodes in the strict sense ($\alpha_k = 0$).

Back to core-periphery.

Additonal results on correlated multiplexity

	Assets-L	Assets-S	Deriv.-L	Deriv.-S	OffBS-L	OffBS-S
Assets-L		0.62***	0.83***	0.15	0.14	0.25*
Assets-S	0.50***		0.49***	0.18	0.08	0.26*
Deriv.-L	0.46***	0.64***		0.11	0.17	0.17
Deriv.-S	0.37***	0.70***	0.85***		-0.00	0.09
OffBS-L	0.26*	0.67***	0.48***	0.55***		0.69***
OffBS-S	0.40***	0.79***	0.55***	0.55***	0.52***	

Table 5 : Correlation indices for *in-strength* (lower triangle) and *out-strength* (upper triangle) centrality.

	Assets-L	Assets-S	Deriv.-L	Deriv.-S	OffBS-L	OffBS-S
Assets-L		0.48***	0.18	0.52***	0.39***	0.45***
Assets-S	0.34**		0.48***	0.66***	0.37***	0.54***
Deriv.-L	-0.24*	-0.10		0.42***	0.29**	0.37***
Deriv.-S	-0.01	0.06	0.34**		0.35**	0.45***
OffBS-L	0.26*	0.18	0.15	0.12		0.45***
OffBS-S	0.25*	0.16	0.01	0.22	0.19	

Table 6 : Correlation indices for *Closeness in* (lower triangle) and *out* (upper triangle) centrality.

Back to correlated multiplexity.

Additonal results on correlated multiplexity (cont.)

	Assets-L	Assets-S	Deriv.-L	Deriv.-S	OffBS-L	OffBS-S
Assets-L						
Assets-S	0.39***					
Deriv.-L	0.25*	0.45***				
Deriv.-S	0.49***	0.54***	0.57***			
OffBS-L	0.55***	0.50***	0.22	0.57***		
OffBS-S	0.41***	0.42***	0.37***	0.30**	0.36***	

Table 7 : Correlation indices for *Betweenness* centrality.

	Assets-L	Assets-S	Deriv.-L	Deriv.-S	OffBS-L	OffBS-S
Assets-L		0.73***	0.56***	0.55***	0.59***	0.47***
Assets-S	0.86***		0.63***	0.62***	0.48***	0.64***
Deriv.-L	0.76***	0.82***		0.70***	0.51***	0.47***
Deriv.-S	0.79***	0.89***	0.90***		0.46***	0.57***
OffBS-L	0.87***	0.86***	0.69***	0.76***		0.65***
OffBS-S	0.83***	0.91***	0.77***	0.84***	0.89***	

Table 8 : Spearman correlation indices for *in-degree* (lower triangle) and *out-degree* (upper triangle) centrality. .

Back to correlated multiplexity.

Additonal results on correlated multiplexity (cont.)

	Assets-L	Assets-S	Deriv.-L	Deriv.-S	OffBS-L	OffBS-S
Assets-L		0.65***	0.59***	0.56***	0.58***	0.60***
Assets-S	0.82***		0.54***	0.57***	0.42***	0.54***
Deriv.-L	0.71***	0.79***		0.55***	0.50***	0.47***
Deriv.-S	0.70***	0.76***	0.87***		0.40***	0.53***
OffBS-L	0.62***	0.71***	0.75***	0.69***		0.73***
OffBS-S	0.67***	0.79***	0.81***	0.73***	0.87***	

Table 9 : Spearman correlation indices for *in-strength* (lower triangle) and *out-strength* (upper triangle) centrality.

	Assets-L	Assets-S	Deriv.-L	Deriv.-S	OffBS-L	OffBS-S
Assets-L		0.60***	0.57***	0.50***	0.56***	0.55***
Assets-S	0.79***		0.54***	0.53***	0.45***	0.51***
Deriv.-L	0.71***	0.81***		0.57***	0.56***	0.43***
Deriv.-S	0.63***	0.76***	0.87***		0.44***	0.48***
OffBS-L	0.63***	0.73***	0.74***	0.66***		0.62***
OffBS-S	0.65***	0.80***	0.80***	0.73***	0.84***	

Table 10 : Spearman correlation indices for *PageRank in* (lower triangle) and *out* (upper triangle) centrality.

Back to correlated multiplexity.

Additonal results on correlated multiplexity (cont.)

	Assets-L	Assets-S	Deriv.-L	Deriv.-S	OffBS-L	OffBS-S
Assets-L		0.49***	0.18	0.50***	0.42***	0.44***
Assets-S	0.39***		0.49***	0.61***	0.43***	0.60***
Deriv.-L	-0.24*	-0.09		0.39***	0.29**	0.35***
Deriv.-S	0.05	0.04	0.35**		0.35***	0.47***
OffBS-L	0.23	0.14	0.11	0.01		0.49***
OffBS-S	0.22	0.08	0.02	0.17	0.04	

Table 11 : Spearman correlation indices for *Closeness in* (lower triangle) and *out* (upper triangle) centrality.

	Assets-L	Assets-S	Deriv.-L	Deriv.-S	OffBS-L	OffBS-S
Assets-L						
Assets-S	0.51***					
Deriv.-L	0.22	0.54***				
Deriv.-S	0.59***	0.61***	0.60***			
OffBS-L	0.39***	0.42***	0.25*	0.36***		
OffBS-S	0.48***	0.44***	0.36***	0.51***	0.57***	

Table 12 : Spearman correlation indices for *Betweenness* centrality.

Back to correlated multiplexity.

Additonal results on systemic importance

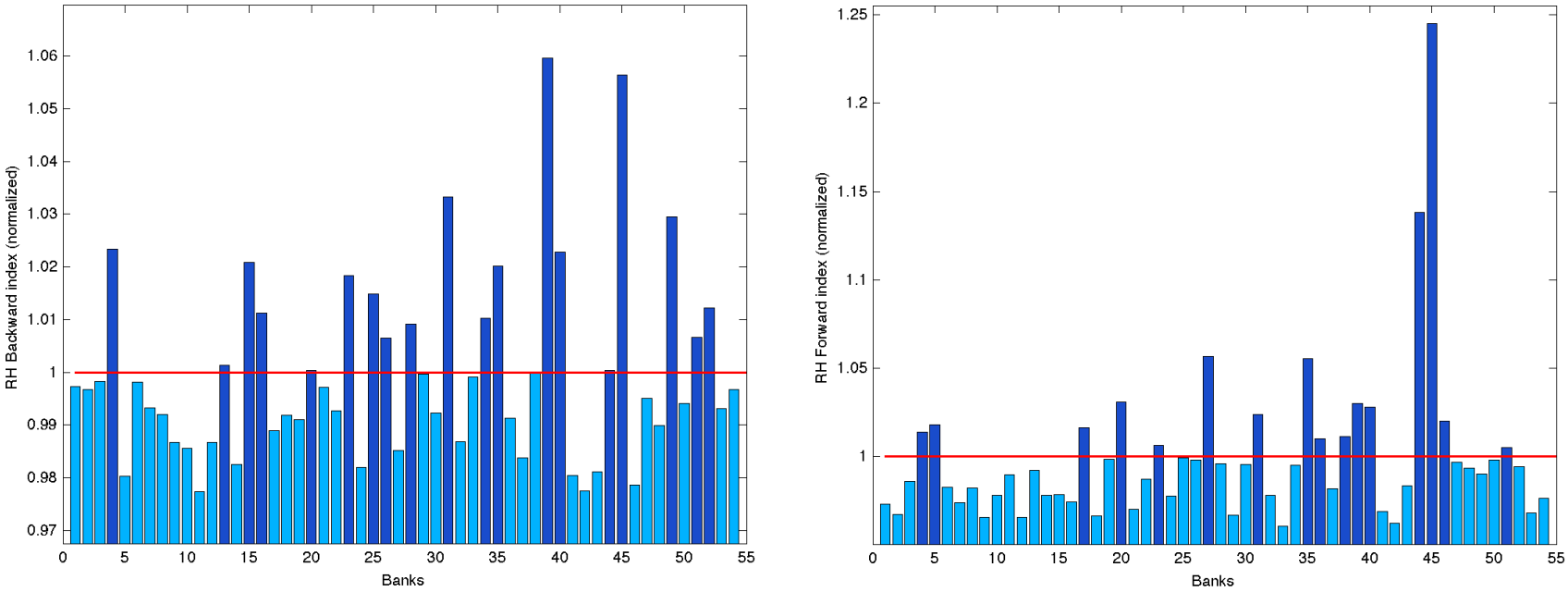

Figure 8 : Normalized backward and forward indices (right and left panel respectively). Banks with a score above 1 are coloured with dark blue.

Back to systemic importance.